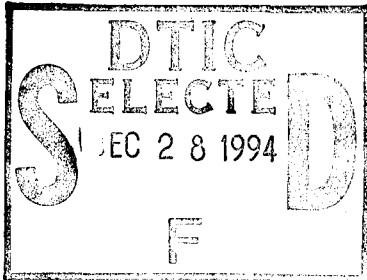


UNIVERSITY OF PENNSYLVANIA
ELECTRICAL ENGINEERING DEPARTMENT



Quarterly Report

**COGNITIVE NETWORKS FOR ATR:
THE ROLES OF BIFURCATION AND CHAOS**

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In previous work we established the importance of developing neural networks that compute with diverse attractors as means for introducing cognition in neural networks. Cognition is the ability of a network to distinguish, on its own, between novel and familiar objects, the latter being the set of objects on which the network is trained and the former being the set of all objects never seen by the network before. Bifurcation between different kinds of attractors in such **cognitive networks** is the mechanism by which cognition is achieved. Cognition is essential in networks intended to operate in complex uncontrolled environment like that encountered in most automated target recognition (ATR) scenarios.

For these reasons we began exploring neural net models that could exhibit all three types of attractors: point, periodic, and chaotic. There is mounting evidence from biology to indicate that the study of such networks can help understand higher-level brain functions such as feature-linking, cognition, separation of object from background, inferencing, and other higher-level functions and can lead to the development of **higher-level neural networks** with enhanced capabilities.

Pulse-coupled networks consisting of spiking or pulsating neurons, which are more biology-oriented than sigmoidal neurons, are of interest to us, not only because they can exhibit all types of attractors in their dynamics, but also because their processing elements are capable, under certain circumstances, of exhibiting synchronicity bifurcation and chaos depending on the nature of their input (activation potential). Accordingly, we have focused our research on studying the dynamics of biology-oriented spiking neuron models especially when they are subjected to periodic activation (driving signals) because periodic activation arises naturally in coupled populations of such neurons when the population enters a phase-locked state. The state vector of such a phase-locked population is then given by the phase of the spike's fired by each neuron measured relative to its periodic activation. The periodic activations of the neurons serve then as a kind of reference signal for phase determination introducing thereby a valuable conceptual link between neural networks and holography and justifying introducing the term **neuroholography**.

To date, our study of spiking biology-oriented integrate-and-fire (I&F) neurons have produced results that allow us to design such neurons with arbitrary degree of complexity in their behavior that include chaotic firing regimes, as illustrated by both computed, and measured **bifurcation diagrams**, **Lyapunov spectra**, and **entropy spectra**. We believe that the

possibility of chaos arising on the signal neuron level may act as an adaptive source of "noise" that could produce a form of annealing in such network to help search for optimal solutions resulting in enhanced network behavior. Verification of this conjecture is an important goal in our research.

The spiking nature of biology-oriented neural networks, however, makes studying their behavior by computer simulation impractical because of the lengthy computing time involved. The use of spiking nets implemented in digital hardware precludes its practical applications. In a recent paper [1], Prange and co-workers argued convincingly that the best way of realizing and studying biology-oriented neural networks is through analog CMOS technology rather than digital hardware. They showed, however, that the number of neurons one can accommodate on a VLSI chip is limited to a hundred or so, even when submicron CMOS technology is used, because of the relatively large size of the neuron/dendrite cell. One way of reducing the size of the neuron/dendrite cell is to reduce the structural complexity of the cell, for example by realizing some of the processes needed in the cells' operation externally to the chip and by coupling these processes to the cell optically. Two such processes are the relaxation mechanism of the I&F neurons and the dendritic-tree response. We have discovered that electron trapping materials, a class of infrared stimuable phosphors, that have been drawing increased attention in optical storage and information processing, have properties that make them attractive for realizing both functions. In particular our work shows that when operated under simultaneous IR and blue light bias, ETMs can be used to provide optical relaxation and pave the way, when used with programmable unijunction transistor (PUT) elements, to forming large arrays of photonic spiking neuron [2]. (See also our preceding quarterly report.)

During the period of this report we have demonstrated the utility of ETMs, under IR/blue light optical bias, for realizing **synapto-dendritic responses**. We were able to show that by varying the levels of IR and/or blue light biases one can alter the blue light impulse response of the ETM, producing orange light emissions with waveform crudely resembling the site-dependent response of biological dendrites to impinging action potentials from other neurons. This means we have now at hand a unique method for crudely emulating synapto-dendritic responses (post-synaptic potentials (PSPs)) in biological neurons in a manner useful for realizing dense optically controlled dendritic trees for use in large-scale biology-oriented optoelectronic spiking neural networks. The results of this work was submitted and accepted for publication in Optics Letters [3].

To understand better how to use the unique features of ETMs for forming large-scale spiking neural networks, we are constructing a simple pulse coupled neural network employing an array of 32 PUT oscillator neurons (PUTONs) and a programmable JPL synapse chip. We expect to describe the results of this work in a future report.

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2. Z. Wen, N.H. Farhat, and S-Y Lin, "Pulsating Neuron Produced by Electron Trapping Materials," Opt. Lett. 19, 1394, (1994).
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